

Large-Area Silicon Detectors for the Advanced Composition Explorer (ACE) Solar Isotope Spectrometer (SIS)

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ABSTRACT

Extensive measurements were made of the thicknesses and dead-layers of the large-area, high-purity silicon detectors used for the Solar Isotope Spectrometer (SIS), an instrument to be launched on the Advanced Composition Explorer (ACE) spacecraft. Tests using accelerated beams of heavy nuclei were also carried out to characterize the completed instrument.

SILICON DETECTORS

The Advanced Composition Explorer is a NASA mission to study the elemental, isotopic and ionic charge-state abundances of particles accelerated on the Sun, within the heliosphere, and in our galaxy. Among the nine instruments on the ACE spacecraft, SIS will detect solar, anomalous, and interplanetary particles with energies from ~10 to ~200 MeV/nucleon. SIS consists of two telescopes, each composed of 17 silicon detectors: two position-sensitive ("matrix") devices form the hodoscope above a 15-element energy-loss stack. All detectors were made by Micron Semiconductor Ltd. using n-type <111> float-zone-refined silicon with ion-implanted electrodes. Matrix detectors are spaced 6 cm apart, octagonal in shape, 50 to 90 μm thick, and have 34 cm^2 active areas that are divided into 64 strips on each face. Strips are 960 μm wide, separated by 40 μm gaps, and oriented in perpendicular directions on opposite sides to provide both X and Y readout. The resulting rms angular resolution is around 0.25° , averaged over all angles. Stack detectors are nearly circular in shape, and have 65 cm^2 active areas. Thicknesses range from 100 to 1000 μm . In each telescope, 14 detectors are grouped into progressively thicker combinations, furnishing seven signal channels (designated T1 through T7), and there is one veto counter at the bottom. Each stack is 6.06 cm deep, incorporating 2.1 g/cm^2 of silicon, and positioned just 0.64 cm below its associated hodoscope. An overview of ACE can be found in Stone et al. (1990). For additional information on SIS, see Cohen et al. (1997). More detailed characterizations of the matrix detectors are in Wiedenbeck et al. (1996 and 1997), and of the stack detectors in Dougherty et al. (1996).

When a fast nucleus penetrates one detector (of thickness L) and stops in the next, the energies deposited (ΔE and E' respectively) follow the relationship:

$$L \sec \theta = R_{Z,M}(E' + \Delta E) - R_{Z,M}(E') \quad (1)$$

where $R_{Z,M}$ is the tabulated range of an isotope with charge Z and mass M . Dead layers introduce small but calculable disparities between the deposited and observed energies. To keep derived mass errors below 0.25 AMU even for iron-group isotopes, total and dead layer thicknesses must be known to within 0.3 % of L for each detector.

Thickness variations across the entire surface of each detector were mapped at the Jet Propulsion Laboratory using a custom-developed dual-arm laser interferometer. See Milliken et al. (1995) for details. Results for one detector are shown in Figure 1. Absolute thickness calibrations were obtained using penetrating beams of ^{36}Ar nuclei at the National Superconducting Cyclotron Laboratory at Michigan State University. Thicker detectors were raster scanned, producing complete maps of the residual-energy recorded by thick, well-characterized stopping detectors placed immediately behind. For thinner devices, high-statistics samplings were taken only at selected spots on each wafer. To calibrate depth versus residual energy, the ^{36}Ar beam was also sent through "slivers" of silicon left over after orientation flats had been cut off our detectors during manufacture. The thicknesses of these slivers were subsequently measured by mechanical means. Final uncertainties around $\pm 0.5 \mu\text{m}$ were obtained.

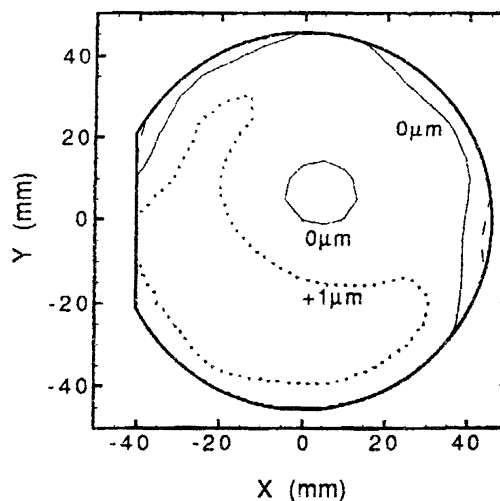


Fig. 1. Thickness variation map of SIS detector T5, in telescope A, obtained by interferometry. Contours are labelled by thickness with respect to the center.

Maps made using radioactive sources of alpha particles revealed that dead layers are uniform to within $\pm 0.05 \mu\text{m}$ on both faces of each detector, and range from 0.15 to 0.40 μm thick. Charge collection response was also mapped as alpha particles entered each detector near, and beyond, the edge of its photolithographically defined active region. Depletion and breakdown characteristics were also studied using these techniques. Detectors which performed poorly in any one of these tests were avoided when detector selections were made for the SIS flight telescopes.

ACCELERATOR DATA

To study the performance of the completed instrument, SIS was exposed to high-energy heavy ions at the GSI accelerator in Darmstadt, Germany. In one test, beams of ^{56}Fe were raster scanned to examine an entire telescope. In addition, a polyethylene target was interposed to cause fragmentation. Figure 2 shows the energies deposited in two successive detectors for data that includes only events in which particles are known to have stopped in T6. The broad, well-separated arcs correspond to different elements. Within these arcs, the isotopic resolution is just discernible.

By treating mass as a continuous variable for each particle, and solving equation (1), we arrive at Figure 3 for the distribution of masses for calcium events. In these preliminary calculations, the thickness of T5 (which consists of a single silicon detector) was assumed to be constant at $\approx 745 \mu\text{m}$, the average over the entire wafer. Only those events which deposited more than 1000 MeV in T6 were included in the analysis.

The hodoscope revealed that most particle trajectories deviated less than 2° from an average of 5° off axis relative to this stack. The corresponding $\sec\theta$ thickness increases were taken into account for these mass calculations. With an angular uncertainty given by the ratio of half a strip width to the matrix detector separation [$\delta\theta = \tan^{-1}(0.5\text{mm}/60\text{mm}) \approx 0.5^\circ$], mass errors were limited to less than $\delta M = M\delta\theta \tan\theta / 0.77 \approx 0.04 \text{ AMU}$ for calcium isotopes. (The factor of 0.77 derives from the exponent of an approximate power-law relationship between range and energy that is valid for the energies encountered here.) The T5 thickness variations of $\pm 1 \mu\text{m}$ shown in Figure 1 contributed an additional $\delta M \approx M\delta L / 0.77L \approx 0.07 \text{ AMU}$ to mass ambiguities. Other contributions

came from electronics noise, multiple scattering, and channeling effects. In this example, however, errors were dominated by Landau and charge-state fluctuations in energy loss. Thickness mapping becomes more important for particles that stop earlier in the telescope, where the detectors are thinner. Systematic errors originating in range-energy tabulations, gain calibrations, detector tilts or misalignments, etc. are largely controllable, if not always as precisely measurable as detector thickness variations. Such errors will be removed as refinements become available.

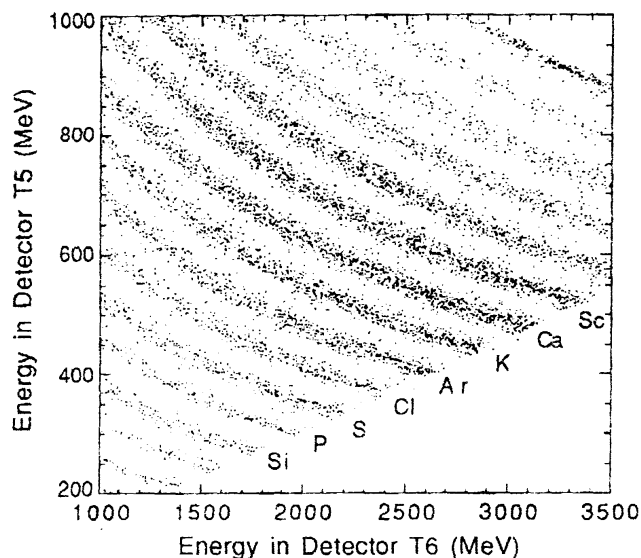


Fig. 2. Energies deposited in channels T5 and T6 of SIS by iron-beam fragments stopping in T6.

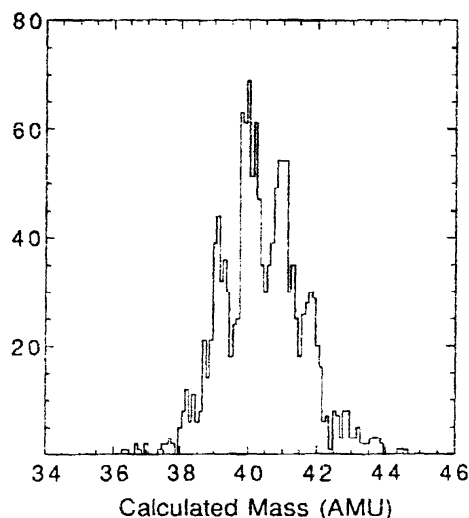


Fig. 3. Calcium isotope distribution calculated from the data in Fig. 2.

THE COSMIC RAY ISOTOPE SPECTROMETER

The Cosmic Ray Isotope Spectrometer (CRIS) is another instrument aboard ACE which consists of similar, though thicker stacks of silicon detectors. CRIS will detect particles of interstellar and galactic origin with energies from ~ 50 to ~ 600 MeV/nucleon. An overview of the instrument can be found in Binns et al. (1997), and details of the ≈ 3 mm thick lithium-drifted detectors are in Allbritton et al. (1996) and Dougherty et al. (1996). Many of the same issues which effect mass resolution in SIS are also of concern in CRIS.

The thickness of each lithium-drifted detector was mapped via the same ^{36}Ar beam method as that used to map the thicker SIS detectors. Absolute thickness calibrations at selected spots were provided by the manufacturer (Lawrence Berkeley National Laboratory) using a two-probe, capacitively-based proximity meter. Dead layers were computed by comparing the energies deposited in both the ^{36}Ar -penetrated and stopping detectors against the calculated thicknesses. These dead layers are comprised of the heavily lithiated junctions, and are several tens of microns deep. Precisions were comparable to those obtained for SIS detectors.

CRIS was also exposed to high-energy heavy nuclei at GSI in Darmstadt. Similar analyses are proceeding to characterize its performance. Since CRIS is designed with detectors that are thicker than those in SIS, to observe higher-energy particles, charge-state fluctuations are therefore less important and mass resolutions are expected to be better.

ACKNOWLEDGMENTS

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